

## III.E.6 Foil Gas Bearing Supported High Speed Centrifugal Anode Gas Recycle Blower

### Objective

Demonstrate the feasibility of using a foil gas bearing supported high-speed centrifugal anode gas recycle blower (FBS-AGRB) to help SECA members meet their SOFC goal of higher efficiency and lower overall system cost.

### Accomplishments

- Designed a prototype FBS-AGRB having the following features:
  - Low-cost design which met “design for manufacturing and assembly” (DFMA) concepts
  - High-temperature capability  $>850^{\circ}\text{C}$
  - Oil-free gas bearings
  - No gas leakage out of the blower
  - No sulfur leakage into the fuel stream from blower components
  - No free silica exposure into the fuel stream
  - No heavy metal leakage into the fuel stream
  - No parasitic cooling required
  - $>40,000$  hour lifetime
  - Maintenance free
  - High-efficiency high-speed motor and centrifugal rotor
  - High-temperature and hostile environment capability
  - Scalability to larger sizes
- Demonstrated the conical foil gas bearing key technology with breadboard testing

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### Introduction

The goal of the Solid State Energy Conversion Alliance (SECA) is to develop commercially-viable ( $\$400/\text{kW}$ ) 3 to 10 kW solid oxide fuel cell (SOFC) systems by year 2010. SOFC power generation systems are attractive alternatives to current technologies in diverse stationary, mobile, and military applications. SOFC systems are very efficient, from 40 to 60 percent in small systems and up to 85 percent in larger co-generation applications. The electrochemical conversion in a SOFC takes place at a lower temperature ( $650^{\circ}\text{C}$  to  $850^{\circ}\text{C}$ ) than combustion-based technologies, resulting in decreased emissions – particularly nitrogen oxides, sulfur oxides, and particulate matter. These systems offer fuel flexibility, as they are compatible with conventional fuels such as hydrogen, coal, natural gas, gasoline or diesel fuel. Despite these advantages, advances in balance-of-plant components must be developed before the SECA program goal can be realized.

SOFC systems that incorporate some recycling of the anode exhaust gas, which is mixed with incoming fresh fuel prior to entering the pre-reformer, have a higher efficiency and offer the potential for lower overall system cost. An anode gas recycling blower (AGRB) is an attractive solution to perform this task.

### Approach

A foil bearing supported high-speed centrifugal anode gas recycle blower was selected to meet the requirements of SOFC systems because of its potential for:

- Low-cost using simple design and less material
- Highest blower efficiency via high speed centrifugal impeller
- High-temperature capability using foil gas bearings, switched reluctance (SR) motor and sensor-less controller
- Contamination-free using oil-free foil gas bearings and hermetically sealed blower
- High reliability from foil gas bearings and SR motor

### Results

The blower was designed for an inlet gas temperature of 600 to  $850^{\circ}\text{C}$ , atmospheric pressure, pressure rise of 4 to 10 inches of water, and a flow of 100 standard liters per minute (slpm), which is nominally

composed of 46 slpm  $H_2O$ , 27 slpm  $CO_2$ , 20 slpm  $H_2$ , and 7 slpm  $CO$ . Overall efficiency meets or exceeds 40% under the aforementioned operating conditions. The unit has a variable speed control with a flow turndown ratio of 5 to 2. The blower unit will have a design life of >40,000 hours, with a 100% duty cycle and 10,000 hour maintenance interval. The unit will be able to tolerate at least 30 thermal cycles, between operating and room temperatures, over its design life. The unit cost of the blower for production rates of >50,000 units was estimated to be less than \$100. Additional design requirements listed below were also addressed:

- Design for scalability
- No gas leakage
- No sulfur leak into the fuel stream
- No free silica exposure into the fuel stream
- No heavy metal leakage into the fuel stream
- No cooling required from the system other than from the process fluid
- No purge gas required
- Blower shaft temperature was estimated to be below water dew point
- Mechanical type seals were not required
- Design explosion-proof
- No corrosion/carbon deposition

Design points for the FBS-AGRB were as follows:

Shaft Speed	>90,000 rpm
Pressure Ratio	1.025
Pressure Rise	25.4 cm of water (10" of water)
Inlet Pressure	1.01 bar (14.69 psia)
Outlet Pressure	1.08 bar (15.06 psia)
Inlet Temperature	850°C (1,562°F)
Outlet Temperature	857.3°C (1,575.2°F)
Gas Constant	0.369 J/kg °C (68.64 ft-lbf/lbm R)
Specific Heat Ratio	1.274
Mass Flow	1.54 g/s (0.204 lbm/min)
Volume Flow	100 slpm
Impeller Isentropic Power	15.6 Watt

A cut-section view of the blower is shown in Figure 1.

Key technologies were incorporated into the blower design, including state-of-the-art aerodynamics, conical gas bearings, SR motor, and sensor-less controller. Design analysis included, critical speed analysis, thermal analysis and stress analysis. The conical bearings were a ground breaking technology best suited for this application and testing was done to confirm their feasibility and applicability to support both radial and thrust loads. An exploded view of a conical bearing is shown in Figure 2.

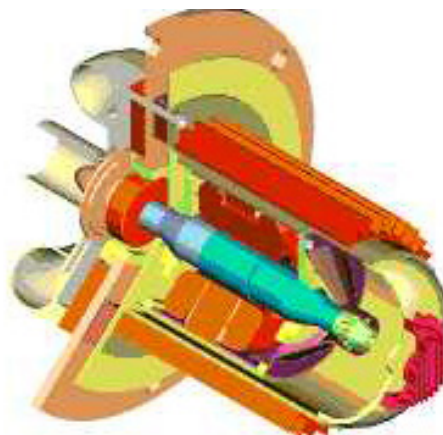


FIGURE 1. Cut-Section View of FBS-AGRB

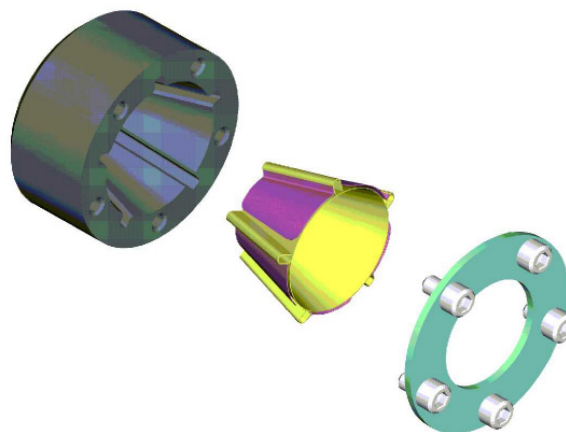


FIGURE 2. Exploded View of Conical Bearing

A breadboard conical bearing test rig was built and is shown with conical test bearing hardware in Figures 3 and 4, respectively. The test rig is capable of testing many combinations of conical bearings at loads and speeds while measuring bearing friction. The rig is comprised of three major sections: the upper section is the housing of the turbine, the mid section is the housing of the journal and thrust bearings, and the lower section is the housing of the conical test bearing and a piston. A fixture was also designed and manufactured for separately measuring breakaway torque and load on the conical bearing. The conical bearing lifted off steadily at different loads and the torque was low, which means power loss is very low. The bearing showed no signs of being stressed. The testing proved the technical feasibility of using conical bearings.



**FIGURE 3.** Breadboard Conical Bearing Test Rig



**FIGURE 4.** Conical Test Bearing Hardware

A cost analysis of the blower was performed by two methods. The first method was based on historical data, past experience at R&D Dynamics and discussions with vendors. The second method was based on automobile standards where cost of existing equipment was scaled to new equipment by varying weight and quantity. Both methods assumed a 50,000 unit production rate per year. Production blower cost varied from \$95 to \$114 per unit. This represents a cost target that is very favorable to meeting overall SOFC system cost goals.

### Conclusions and Future Directions

- Key blower technologies were proven by extensive design and analysis.
- The high-temperature blower design evolved to be a successful design which can achieve the SECA goal.
- Conical bearing breadboard testing proved the technical feasibility of conical bearings.
- The blower cost was estimated to be less than \$100 at a production volume of 50,000 units/year.

Phase I is complete. Work needs to be continued in Phase II as follows:

- Develop a prototype blower
- Test at high-temperature condition
- Incorporate rigorous “design for manufacturing and assembly” techniques to reduce cost
- Demonstrate blower to SECA members
- Test blowers at SECA member’s fuel cell systems

### FY 2006 Publications/Presentations

1. “Foil Bearing Supported High-Speed Centrifugal Blower,” SECA Core Technology Program Peer Review, October 25-26, 2005, Lakewood, CO.